Statement of

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Good morning Chairman Babin, Ranking Member Bera, Members of the Committee and staff. I appreciate the opportunity to be here this morning to discuss how in-space propulsion will enable and enhance the Nation's space exploration efforts together with the Space Launch System (SLS) and Orion. Furthermore, I, along with the rest of Aerojet Rocketdyne employees across the country, appreciate the relentless work the Members and staff of this Committee have put forth to ensure that SLS, Orion, and the Nation's space program are a success. Your commitment to exploration and discovery should be lauded.

This is a time of great excitement and inspiration within the space community and for that matter across the country and around the world. We are putting the people in place and building the systems necessary to get humankind back to deep space and on to Mars and beyond starting in the early 2020s with the Deep Space Gateway.

<u>Aerojet Rocketdyne Background</u>

Aerojet Rocketdyne is a world leader in power and propulsion, supporting the Nation's defense, civil and commercial space efforts for over 70 years. Aerojet Rocketdyne has launched every astronaut from U.S. soil, and has been part of every U.S. mission to Mars. Among the highlights of our mission success heritage we have:

- powered every U.S. launch vehicle since the inception of the Nation's space program (Titan, Saturn, Space Shuttle, all Atlas, Delta IV and Delta II and the Space Launch System);
- flown on 135 Space Shuttle missions with 100% mission success;

- propelled spacecraft to every planet in our solar system; we're 7 for 7 landings on Mars, and we have even gone interstellar with Voyager;
- power and propulsion systems on NASA's Crew and Cargo service vehicles to the International Space Station;
- provided more than 90% of power systems to the International Space Station inlcuding the newly installed Li-Ion batteries;
- electric propulsion on more than 160 spacecraft of the approximately 250 electric propulsion spacecraft in orbit. (Figure 1)

Expanded Human Presence in Deep Space

As NASA looks to expand human presence in the solar system, starting with missions to lunar orbit and on to Mars, development of efficient in-space transportation systems is critical. Solar Electric Propulsion (SEP) is key to a sustainable architecture by enabling efficient transfer of cargo, habitats and payloads to deep space destinations in advance of astronaut arrival.

To provide a sense of scale, today we can land one metric ton on the surface of Mars; for a human mission we need to land 80 metric tons of supplies and equipment. Mars missions will also send humans much farther than ever before. This combination of heavier payloads combined with the need to travel over greater distances drives us to seek a solution that takes advantage of strategic logistics planning. An analogy which may help explain this approach is the way that military deployments are conducted today. First, the heavy equipment, supplies, and other logistical items are pre-deployed by large cargo ships and planes to the region. Then, once the equipment, barracks etc. are in place, the troops follow by faster air transport. SEP systems are the equivalent to the cargo ship for deep space missions.

SEP systems under development now by NASA and Aerojet Rocketdyne reduce the amount of propellant needed for deep space missions by a factor of 10. This is important because it costs as much to launch propellant as it does to launch scientific instruments or other mission critical equipment. SEP makes it possible to launch larger, heavier payloads thereby reducing the number of launches needed and the taxpayer cost for the total mission.

SEP Overview and Applications

Electric propulsion uses energy from sources other than chemical bonds to provide acceleration of propellant to obtain thrust. Because the energy is not limited to a chemical reaction, SEP can accelerate propellant to very high velocities, resulting in the use of less propellant to accomplish the same movement of the spacecraft.

A schematic of a typical SEP system is shown in Figure 2. The elements include the spacecraft's solar arrays which provide the power by converting energy from the Sun into electricity. This electrical power is then channeled into the propulsion devices through a series of electrical converters and regulators known collectively as the Power Management and Distribution system. For higher power systems, there are multiple thruster "strings." For example, in a 40 kW system there would be three active strings of 13 kW each. Each string consists of a thruster (Hall or ion), a Power Processing Unit (PPU), and a Propellant Distribution and Control System that regulates and supplies propellant to the thruster strings. There is also a digital interface to the spacecraft control computer that allow commands and telemetry to pass back and forth.

There are a number of applications for SEP including stationkeeping, repositioning, and orbit-raising for commercial, civil, national security and defense satellites. Additionally for deep space exploration, SEP enables bold missions such as visits to multiple asteroids accomplished by the DAWN mission. Building on the legacy of DAWN, SEP is an enabler for ambitious planetary missions such as sample returns in NASA's search for life on Mars and the Ocean Worlds. As mentioned previously, SEP will be used to preposition cargo in advance of human landings on other planetary surfaces.

SEP Development Challenges

We are well on our way to having efficient in-space transportation with SEP. We must continue to adequately fund these development efforts to ensure we will have the first human footprints on Mars in the 2030s. The primary challenge facing high power SEP development is the risk of losing focus as we go through the critical transition period from development to flight demonstration and subsequently, operational use. This requires a stable budget and a constancy of purpose. Everything we do should be with the goal of landing humans on Mars in the 2030s. As stated by the National Research Council in their Pathways to Exploration report, the pathway should be "characterized by logical feed-forward of capabilities." Currently we are on a development path that will result in a SEP system capability in the 100 kW – 200 kW total power range. This is more than adequate for early outpost missions to Mars, as depicted in the architectural approach shown in Figure 3.

As SEP is scaled up for NASA's deep space cargo missions, attention must be given to managing the power transfer from the solar arrays to the thrusters. Because electric propulsion is inherently low thrust, trip times are longer and can only be reduced by increasing the power to the thrusters. Therefore, it is important to ensure that power is transferred as efficiently as possible. Efficiency also plays a critical role in the heat rejection design of the spacecraft because power losses become heat that must be rejected, which drives the size and mass of the thermal radiators. This is especially important as power levels increase to several hundred kilowatts. A power system from a traditional spacecraft, typically sized at 10 – 20 kW, cannot be adapted for a high-power SEP cargo vehicle. Current commercial spacecraft power systems are designed to power payloads, whereas a SEP system directs the power to the electric propulsion thrusters.

Current SEP Development Programs at Aerojet Rocketdyne

Aerojet Rocketdyne is currently working on three separate SEP systems under contract to NASA. One is focused on deep space science missions; the second is focused on supporting human exploration of deep space; and the third addresses longer term technology development. The first two, NEXT-C and AEPS, have missions that are planned to launch within the next 2 – 5 years. In addition, Aerojet Rocketdyne is teamed with Sierra Nevada Corp. to develop a concept for a power and propulsion module that will include high power SEP for NASA's NextSTEP-2 habitation studies.

1) The NEXT-C xenon ion engine system is tailored to the needs of NASA's Science Mission Directorate. Under the program, a complete system is being developed that includes thrusters, power processors, and xenon flow controllers for delivery to NASA for use on science missions. One such mission is the Double Asteroid Redirect Target (DART) mission scheduled to launch in 2020. NEXT-C is moving forward toward the program Critical Design Review, which will be followed by build of the flight units for delivery to NASA.

2) Under the Advanced Electric Propulsion System (AEPS) program, Aerojet Rocketdyne is developing a flight version of the NASA HERMES 13 kW Hall thruster and a flight power processor, plus a xenon flow control system. This will result in the most powerful Hall thruster system ever flown when it is delivered in 2019. The program is fully funded and is working toward a Preliminary Design Review in August of 2017. Just this month, a series of tests was successfully completed at NASA Glenn Research Center that demonstrated stable operation of the system by the PPU over a range of conditions. This system will be demonstrated on a flight in 2021/2022 to prove readiness for use in a Mars cargo vehicle that would pre-position assets required by the astronauts during the first human mission to the red planet in the early 2030s. Originally, this demonstration was to be on the Asteroid Redirect Mission (ARM). In light of the recently announced cancellation of ARM, NASA has directed Aerojet Rocketdyne to continue working toward the 2019 delivery date so that the SEP demonstration can occur in 2021/2022.

3) The 100 kW Nested Hall Thruster is being developed as part of the NextSTEP program within NASA’s Advanced Exploration Systems. A very high power thruster and a modular PPU are being developed, scalable from 50 kW to 200 kW. As part of the NextSTEP program, we will demonstrate the steady-state firing of the thruster and PPU at 100 kW for 100 hours continuously.

Aerojet Rocketdyne is committed to this nation’s space exploration program from the ground up, and I look forward to answering your questions about our advanced in-space development activities.

Thank you.

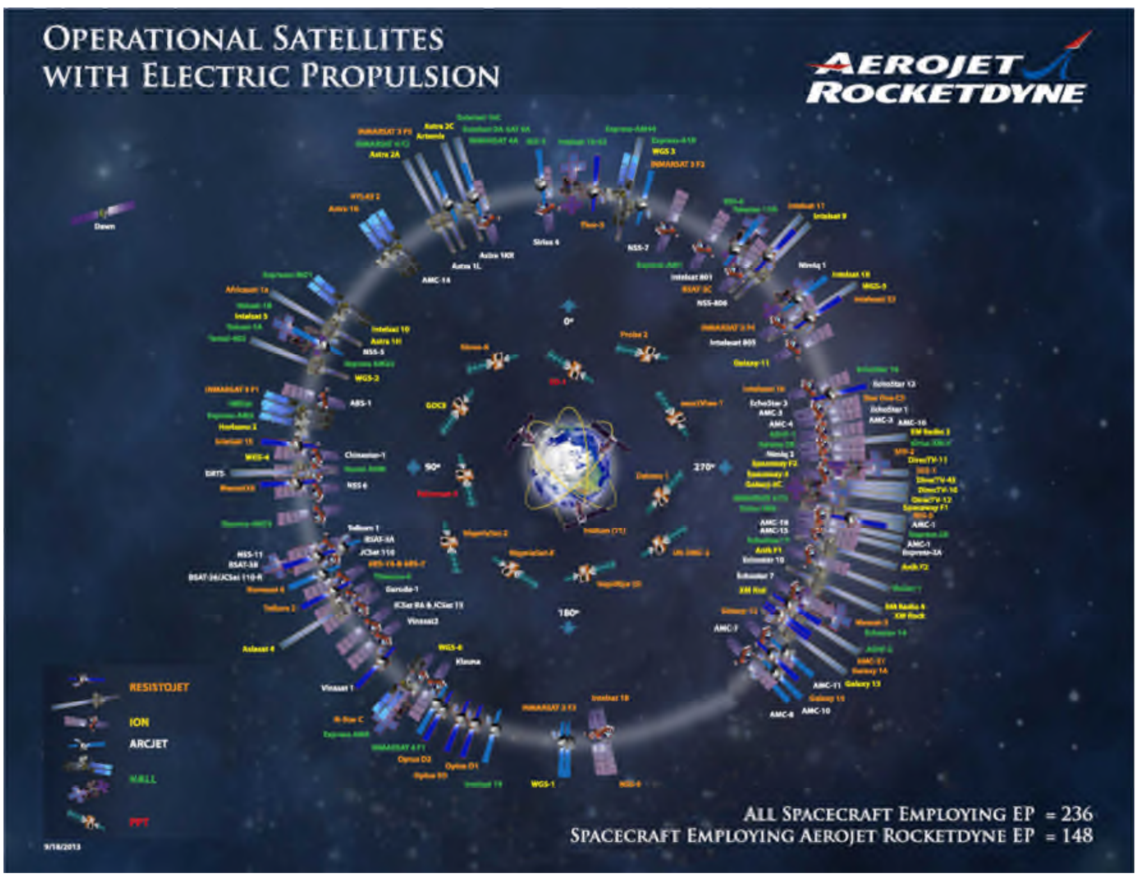

Figure 1 – Operational Satellites with Electric Propulsion

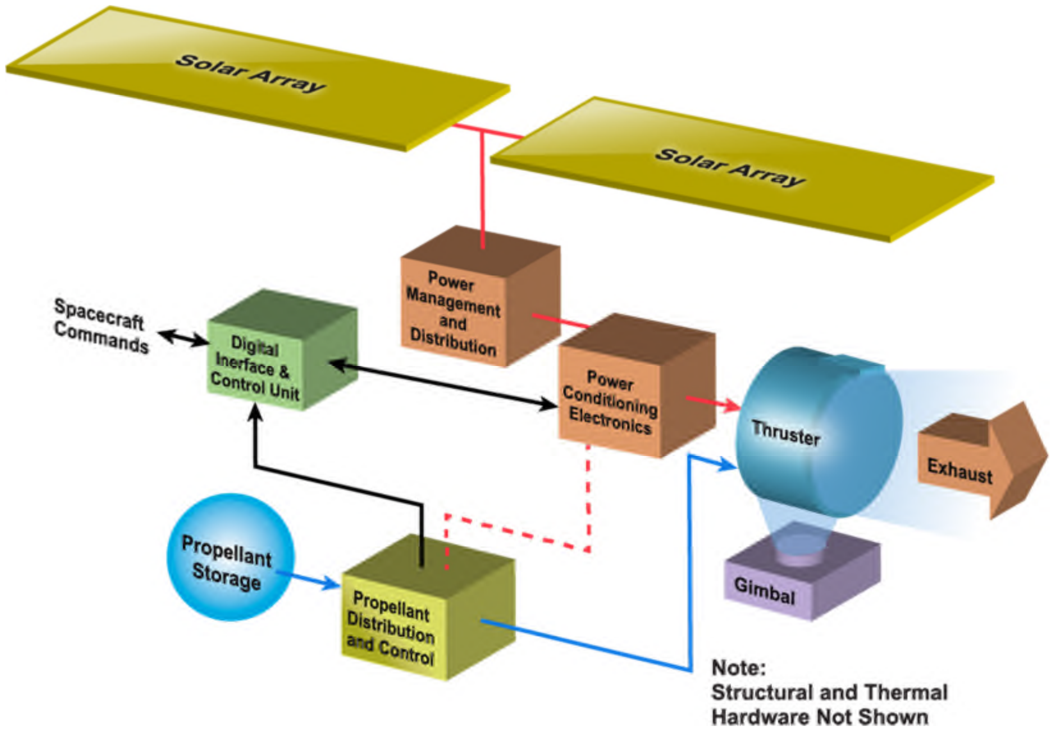

Figure 2 - Typical SEP System Schematic

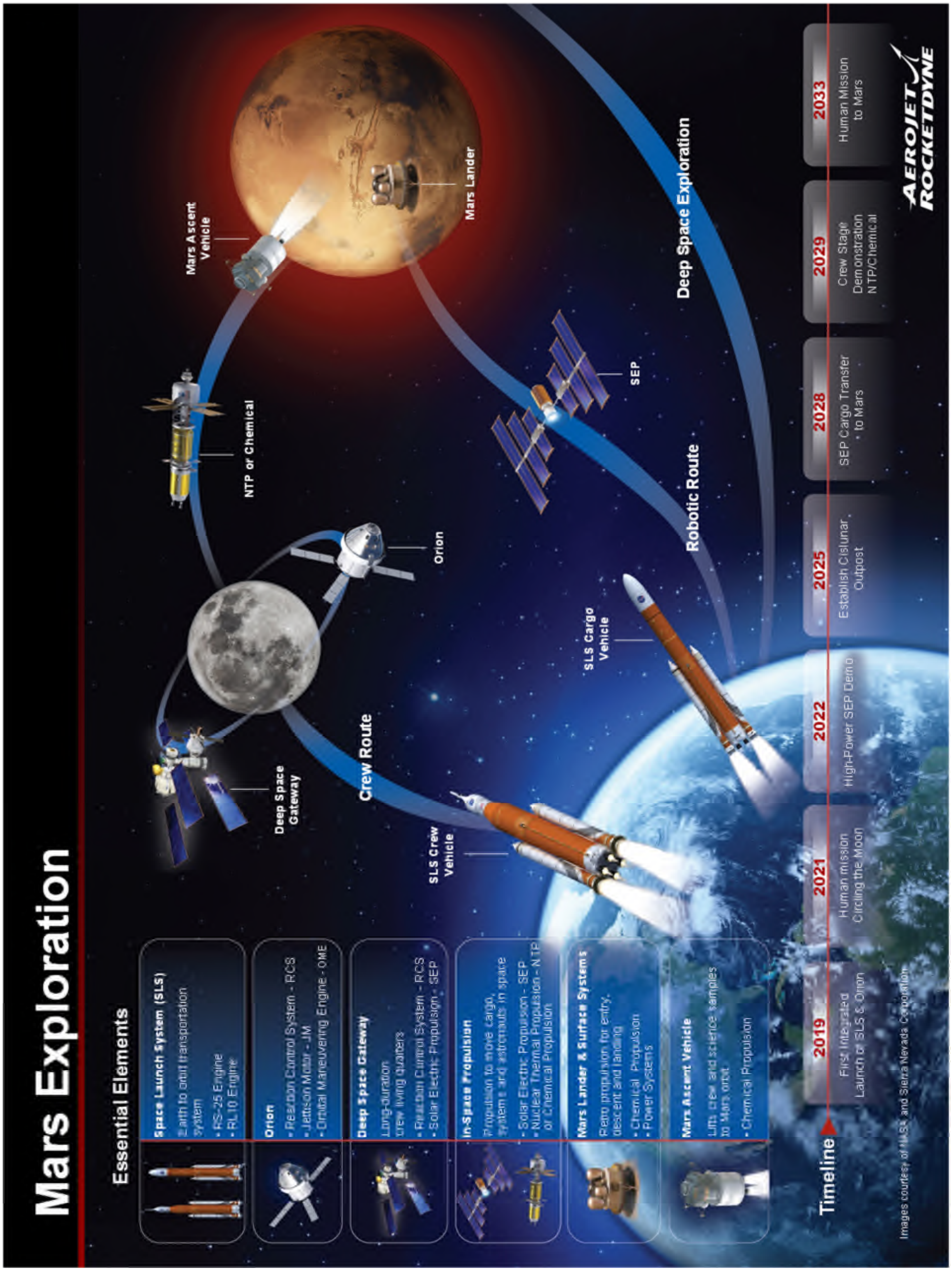

Figure 3. Aerojet Rocketdyne architecture concept for deep space exploration

Summary of Major Points

Solar electric propulsion (SEP) will play an important role in human missions to Mars by efficiently pre-deploying cargo and supplies.

SEP enables multiple planetary robotic missions, such as sample return from small bodies and Mars.

Electric propulsion is a mature technology used on more than 200 commercial and DoD satellites on orbit today.

Technology development of high power (10 kW – 100 kW) electric propulsion is being funded now by NASA.

A mission demonstrating high power SEP capability is planned for the 2021/ 2022 time frame.

Challenges to development are more at a system level, especially efficient power transmission and regulation at 40 kW – 400 kW

Other challenges are more programmatic: maintaining focus and constancy of purpose.